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TITLE: Giant Magnetoresistive Element

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GIANT MAGNETORESISTIVE ELEMENT

BACKGROUND OF THE INVENTION

1. Field of the Invention

5   The present invention relates to a giant magnetoresistive element used for a hard disk device, a magnetic sensor, and the like, and a method of manufacturing the same.

2. Description of the Related Art

10   In a giant magnetoresistive element (GMR) used for a hard disk device, a magnetic sensor, and the like, an improvement in output sensitivity and narrowing of a track have recently been advanced with increases in the recording density.

15   In order to improve the output sensitivity, a magnetic moment (areal moment) per unit area of a free magnetic layer is conventionally decreased by thinning the free magnetic layer to facilitate magnetization rotation of the magnetic moment. However, with the thin free magnetic layer,

20 Barkhausen noise, thermal fluctuation noise, and the like are increased to cause the problem that a SN ratio cannot be increased even by increasing the output sensitivity. Also, a hard bias system using a permanent magnet film is conventionally used for the free magnetic layer. However, in

25 the hard bias system, magnetization is strongly fixed at both side ends of the free magnetic layer adjacent to the permanent magnet film to produce dead zones, thereby causing the probability that the entire track region becomes a dead

zone when narrowing of the track is advanced. Therefore, it is predicted that the hard bias system using the permanent magnet film is difficult to comply with a higher recording density.

5   Therefore, an exchange bias system has recently been proposed as the bias system for the free magnetic layer. As is generally known, a GMR element has a structure in which a first antiferromagnetic layer, a pinned magnetic layer, a nonmagnetic material layer and a free magnetic layer are

10   laminated in turn. In the use of the exchange bias system, second antiferromagnetic layers and electrode layers are further formed on both sides of the free magnetic layer so that the track width of the GMR element is controlled by the distance between the second antiferromagnetic layers in the

15   track width direction. In the use of the exchange bias system, no dead zone occurs, and thus output sensitivity can be possibly secured even with advances in track narrowing.

However, in the free magnetic layer, an exchange interaction acts between adjacent spins to orient the

20   adjacent spins in parallel directions, and thus a distance corresponding to the strength of the exchange interaction between the adjacent spins is required for rotating the spins by an angle according to the strength of an external magnetic field. The strength of the exchange interaction can be

25   represented by an exchange stiffness constant (exchange interaction constant). As the exchange stiffness constant increases, a spin direction cannot be rapidly changed to increase a distance required for spin rotation. When the

distance required for spin rotation is increased,
magnetization fixing at the ends of the track width region is
strongly transmitted to the central portion, thereby
decreasing the output sensitivity. This tendency becomes

5   remarkable as the track width dimension decreases, and thus
the output sensitivity cannot be easily secured even by using
the exchange bias system. As a possible countermeasure
against this, the free magnetic layer is made of a material
having a small exchange stiffness constant. However, the use

10   of the material having a small exchange stiffness constant
undesirably decreases the Curie temperature. Also, the
selection of the material has a limitation.

Furthermore, the use of the exchange bias system has the
following problem.

15   Since a sensing current flows in the free magnetic layer
through the antiferromagnetic layers having extremely higher
resistivity than that of the electrode layers, the element
resistance is increased. When the element resistance is
increased, impedance is also increased to easily produce

20   high-frequency noise, thereby failing to increase the SN
ratio even with the improved output sensitivity.

SUMMARY OF THE INVENTION

The present invention has been achieved in consideration

25   of the problem of the use of a conventional exchange bias
system, and it is an object of the present invention to
provide a giant magnetoresistive element capable of securing
high output sensitivity even with advances in track narrowing,

and a method of manufacturing the same.   Another object of

the present invention is to provide a giant magnetoresistive

element capable of decreasing the element resistance, and a

method of manufacturing the same.

5   The present invention has been achieved with attention

to the point that output sensitivity can be improved by using

a demagnetizing field produced in a free magnetic layer in

the track width direction thereof, and the point that the

element resistance can be decreased by supplying a sensing

10   current without passing through an antiferromagnetic layer.

A giant magnetoresistive element of the present

invention comprises a first antiferromagnetic layer, a pinned

magnetic layer formed on the first antiferromagnetic layer so

that the magnetization direction is pinned by an exchange

15   coupling magnetic field with the first antiferromagnetic

layer, a nonmagnetic material layer formed on the pinned

magnetic layer, a free magnetic layer formed on the

nonmagnetic material layer so that the magnetization

direction of a central portion changes with an external

20   magnetic field, nonmagnetic layers formed on both side

portions of the free magnetic layer in the track width

direction, ferromagnetic layers formed on the respective

nonmagnetic layers, and second antiferromagnetic layers

formed on the respective ferromagnetic layers to align the

25   magnetization direction of each ferromagnetic layer in a

direction perpendicular to the magnetization direction of the

pinned magnetic layer, wherein at least the free magnetic

layer, the nonmagnetic layers and the ferromagnetic layers

have continuous end surfaces at both sides in the track width direction.

In the above-described construction, magnetostatic coupling occurs between the free magnetic layer and the ferromagnetic layers at both end surfaces thereof, and thus a demagnetizing field applied in the free magnetic layer in the track width direction thereof is weakened by the magnetostatic coupling. Namely, even if the demagnetizing field is increased by narrowing the track, disturbance of magnetization of each of the free magnetic layer and the ferromagnetic layers can be sufficiently suppressed to secure high stability of a reproduction waveform. Also, the magnetization directions of both side portions of the free magnetic layer and the ferromagnetic layers are strongly pinned by the second antiferromagnetic layers. Therefore, even if the demagnetizing field is increased by narrowing the track, there is no probability of side reading.

The ratio FW/FL of the dimension FW of the free magnetic layer in the track width direction to the dimension FL of the ferromagnetic layers in the track width direction is preferably 1.1 to 2.0. With a FW/FL ratio within this range, magnetization of a track width region (a central portion of the free magnetic layer) easily rotates with an external magnetic field to improve output sensitivity. The dimension FL of the free magnetic layers in the track width direction is a total dimension FL1+FL2 of the dimensions of FL1 and FL2 of the respective ferromagnetic layers in the track width direction.

The above-described giant magnetoresistive element preferably further comprises electrode layers formed in contact with the upper surfaces of the respective second antiferromagnetic layers and contact with both end surfaces

5   of the layers ranging from the respective antiferromagnetic layers to the pinned magnetic layer in the track width direction. Each of the electrode layers comprises a first electrode layer formed in contact with the end surfaces of the layers ranging from the pinned magnetic layer to each

10 second antiferromagnetic layer at each side in the track width direction, and a second electrode layer formed on the first electrode layer and each second antiferromagnetic layer. In this construction, a sensing current can be supplied without passing through the second antiferromagnetic layers

15 having extremely higher resistivity than that of a conductive material for forming the electrode layers. Therefore, the element resistance can be sufficiently suppressed to suppress the occurrence of high-frequency noise, thereby improving the SN ratio.

20   Each of the second antiferromagnetic layers may comprise a lower antiferromagnetic layer laminated on each ferromagnetic layer, and an upper antiferromagnetic layer. In this case, the lower antiferromagnetic layers are preferably 20 Å to 50 Å in thickness. With the lower

25 antiferromagnetic layers each having a thickness in this range, the lower antiferromagnetic layers do not assume antiferromagnetic properties in a stage in which only the lower antiferromagnetic layers are formed (the upper

antiferromagnetic layers are not formed). Therefore, even in a first heat treatment for pinning the magnetization direction of the pinned magnetic layer, no or a weak exchange coupling magnetic field occurs between each of the lower

5　antiferromagnetic layers and the ferromagnetic layer. On the other hand, in a stage in which the upper antiferromagnetic layers are formed on the lower antiferromagnetic layers, a heat treatment produces great exchange coupling magnetic fields between the ferromagnetic layers and the lower

10　antiferromagnetic layers. Therefore, the total thickness of each lower antiferromagnetic layer and upper antiferromagnetic layer is preferably 80 Å to 300 Å.

A nonmagnetic protective layer may be interposed between each lower antiferromagnetic layer and upper

15　antiferromagnetic layer, or a constituent element of the nonmagnetic protective layer may be mixed in the lower antiferromagnetic or upper antiferromagnetic layers. However, the thickness of each nonmagnetic protective layer is preferably 3 Å or less so that the lower antiferromagnetic

20　and upper antiferromagnetic layers can function as an antiferromagnetic layer as a unit. The constituent element of the nonmagnetic protective layers is preferably at least one of Ru, Rh, Pd, Ir, Os, Re, Cr, Cu, Pt, and Au. The nonmagnetic protective layers function as antioxidation films

25　for protecting the surfaces of the lower antiferromagnetic layers from oxidation in the manufacturing process.

In a first aspect of the present invention, a method of manufacturing a giant magnetoresistive element comprises (a)

a step of laminating a first antiferromagnetic layer, a pinned magnetic layer, a nonmagnetic material layer, a free magnetic layer and a nonmagnetic layer in order on a substrate; (b) a step of performing a first heat treatment to

5   pin the magnetization direction of the pinned magnetic layer by an exchange coupling magnetic field produced between the first antiferromagnetic layer and the pinned magnetic layer; (c) a step of cleaning the surface of the nonmagnetic layer by low-energy ion milling; (d) a step of laminating a

10   ferromagnetic layer and a second antiferromagnetic layer in order on the nonmagnetic layer; (e) a step of forming a resist layer on a region of the second antiferromagnetic layer corresponding to a track width region; (f) a step of removing exposed portions of at least the second

15   antiferromagnetic layer, the ferromagnetic layer, the nonmagnetic layer and the free magnetic layer, which are partially exposed from both sides of the resist layer in the track width direction; (g) a step of removing the resist layer and forming an electrode layer on regions of the second

20   antiferromagnetic layer out of the track width region; (h) a step of partially removing the second antiferromagnetic layer, the ferromagnetic layer and the nonmagnetic layer within the track width region by etching using the electrode layer as a mask; and (i) a step of performing a second heat treatment to

25   pin the magnetization direction of the ferromagnetic layer in a direction perpendicular to the magnetization direction of the pinned magnetic layer by exchange coupling produced between the second antiferromagnetic layer and the

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ferromagnetic layer, wherein in the steps (a) and (d), the free magnetic layer and the ferromagnetic layer are formed so that the magnetic moment per unit area of the free magnetic layer is larger than that of the ferromagnetic layer, in the

5   step (c), the nonmagnetic layer is removed by the low-energy ion milling to a thickness with which RKKY coupling energy produced between the free magnetic layer and the ferromagnetic layer is a first peak or second peak value for antiparallel alignment, and in the step (f), the layers

10 ranging from the second antiferromagnetic layer to the free magnetic layer are left to have continuous surfaces at both end surfaces in the track width direction.

In a second aspect of the present invention, a method of manufacturing a giant magnetoresistive element comprises (m)

15 a step of laminating a first antiferromagnetic layer, a pinned magnetic layer, a nonmagnetic material layer, a free magnetic layer and a nonmagnetic layer, a ferromagnetic layer, a lower antiferromagnetic layer and a nonmagnetic protective layer in order on a substrate; (n) a step of performing a

20 first heat treatment to pin the magnetization direction of the pinned magnetic layer by an exchange coupling magnetic field produced between the first antiferromagnetic layer and the pinned magnetic layer; (o) a step of cleaning the surface of the nonmagnetic protective layer by low-energy ion

25 milling; (p) a step of laminating an upper antiferromagnetic layer on the nonmagnetic protective layer; (r) a step of forming a resist layer on a region of the upper antiferromagnetic layer corresponding to a track width

region; (s) a step of removing exposed portions of at least the upper antiferromagnetic layer, the nonmagnetic protective layer, the lower antiferromagnetic layer, the ferromagnetic layer, the nonmagnetic layer and the free magnetic layer,

5 which are partially exposed from both sides of the resist layer in the track width direction; (t) a step of removing the resist layer and forming an electrode layer on regions of the upper antiferromagnetic layer out of the track width region; (u) a step of partially removing the upper

10 antiferromagnetic layer, the nonmagnetic protective layer, the lower antiferromagnetic layer, the ferromagnetic layer and the nonmagnetic layer within the track width region by etching using the electrode layer as a mask; and (v) a step of performing a second heat treatment to pin the

15 magnetization direction of the ferromagnetic layer in a direction perpendicular to the magnetization direction of the pinned magnetic layer by exchange coupling produced between the lower antiferromagnetic layer and the ferromagnetic layer, wherein in the step (m), the free magnetic layer and the

20 ferromagnetic layer are formed so that the magnetic moment per unit area of the free magnetic layer is larger than that of the ferromagnetic layer, and the nonmagnetic layer is formed to a thickness with which RKKY coupling energy produced between the free magnetic layer and the

25 ferromagnetic layer is a first peak or second peak value for antiparallel alignment, and in the step (s), the layers ranging from the upper antiferromagnetic layer to the free magnetic layer are left to have continuous surfaces at both

end surfaces in the track width direction.

The ratio FW/FL of the dimension FW of the free magnetic layer in the track width direction to the dimension FL of the ferromagnetic layers in the same direction is preferably 1.1

5 to 2.0.

In each of the aspects of the present invention, the electrode layer may comprise a first electrode layer in contact with the end surfaces of the layers from the second antiferromagnetic layer to the pinned magnetic layer at each

10 side in the track width direction, and a second electrode layer disposed on the first electrode layer and the second antiferromagnetic layer. Namely, in the first aspect, in place of the step (g), a step (j) of forming a first electrode layer in contact with the end surfaces of at least

15 the layers ranging from the second antiferromagnetic layer to the pinned magnetic layer at each side in the track width direction, (k) a step of removing the resist layer, (l) a step of forming a second electrode layer on the first electrode layer and the second antiferromagnetic layer

20 outside the track width region may be performed. In the second aspect, in place of the step (t), a step (w) of forming a first electrode layer in contact with the end surfaces of at least the layers ranging from the upper antiferromagnetic layer to the pinned magnetic layer at each

25 side in the track width direction, (x) a step of removing the resist layer, (y) a step of forming a second electrode layer on the first electrode layer and the upper antiferromagnetic layer outside the track width region may be performed.

The lower antiferromagnetic layer is preferably deposited to a thickness of 20 Å to 50 Å. With a thickness within this range, the lower antiferromagnetic layer do not assume the antiferromagnetic properties in the stage in which

5   only the lower antiferromagnetic layer is formed (the upper antiferromagnetic layer is not formed). Therefore, even in a first heat treatment for pinning the magnetization direction of the pinned magnetic layer, no or a weak exchange coupling magnetic field occurs between the lower antiferromagnetic

10 layer and the ferromagnetic layer. On the other hand, in the stage in which the upper antiferromagnetic layer is formed on the lower antiferromagnetic layer, a heat treatment produces a great exchange coupling magnetic field between the ferromagnetic layer and the lower antiferromagnetic layer.

15 Therefore, the total thickness of the lower antiferromagnetic layer and upper antiferromagnetic layer is preferably 80 Å to 300 Å.

The nonmagnetic protective layer is preferably deposited to a thickness of 3 Å to 10 Å so that oxidation of the lower

20 antiferromagnetic layer can be prevent, and the nonmagnetic protective layer can easily be removed. The nonmagnetic protective layer is preferably controlled to a thickness of 3 Å or less by low-energy ion milling. In this case, the lower and upper antiferromagnetic layers are coupled with each

25 other through the nonmagnetic protective layer to function as an antiferromagnetic layer as a unit.

Each of the free magnetic layer and the ferromagnetic layer may comprise any one of a NiFe alloy, Co, a CoFe alloy,

a CoNi alloy, and a CoFeNi alloy. The free magnetic layer and ferromagnetic layer are preferably made of the same magnetic material. When the free magnetic layer and ferromagnetic layer are made of the same magnetic material,

5 the thickness of the ferromagnetic layer is made smaller than that of the free magnetic layer so that the magnetic moment per unit area of the free magnetic layer is larger than that of the ferromagnetic layer. When each of the free magnetic layer and ferromagnetic layer comprises a single layer, at

10 least one of the free magnetic layer and ferromagnetic layer preferably comprises a CoFeNi alloy. Furthermore, when each of the free magnetic layer and ferromagnetic layer comprises a plurality of layers, the free magnetic layer preferably comprises a laminate of a NiFe alloy layer and a CoFe alloy

15 layer, and the ferromagnetic layer preferably comprises a laminate of a CoFe alloy layer and a NiFe alloy layer.

The nonmagnetic layer is preferably composed of at least one of Ru, Rh, Pd, Ir, Os, Re, Cr, Cu, Pt, and Au, and particularly the nonmagnetic layer is preferably composed of

20 Ru or Cu.

The first antiferromagnetic and/or second antiferromagnetic layer preferably comprises a PtMn alloy, a X-Mn (wherein X is at least one element of Pd, Ir, Rh, Ru, Os, Ni, and Fe) alloy, or a Pt-Mn-X' (wherein X' is at least one

25 element of Pd, Ir, Rh, Ru, Au, Ag, Os, Cr, Ni, Ar, Ne, Xe, and Kr) alloy. With the first antiferromagnetic layer and/or second antiferromagnetic comprising any one of these alloys, a large exchange coupling magnetic field can be produced

between the first antiferromagnetic layer and the pinned
magnetic layer and/or the second antiferromagnetic layer and
the ferromagnetic layer.

5   BRIEF DESCRIPTION OF THE DRAWINGS

    Fig. 1 is a partial sectional view showing the structure
of a giant magnetoresistive element (GMR element) according
to a first embodiment of the present invention, as viewed
from a surface facing a recording medium;

10   Fig. 2 is a drawing showing a step of a method of
manufacturing the GMR element shown in Fig. 1;

    Fig. 3 is a drawing showing a step after the step shown
in Fig. 2;

    Fig. 4 is a drawing showing a step after the step shown
15   in Fig. 3;

    Fig. 5 is a drawing showing a step after the step shown
in Fig. 4;

    Fig. 6 is a drawing showing a step after the step shown
in Fig. 5;

20   Fig. 7 is a drawing showing a step after the step shown
in Fig. 6;

    Fig. 8 is a drawing showing a step after the step shown
in Fig. 7;

    Fig. 9 is a partial sectional view showing the structure
25   of a GMR element according to a second embodiment of the
present invention, as viewed from a surface facing a
recording medium;

    Fig. 10 is a drawing showing a step of a method of

manufacturing the GMR element shown in Fig. 9;

Fig. 11 is a drawing showing a step after the step shown in Fig. 10;

Fig. 12 is a drawing showing a step after the step shown in Fig. 11;

Fig. 13 is a drawing showing a step after the step shown in Fig. 12;

Fig. 14 is a partial sectional view showing a second electrode layer according to another embodiment; and

Fig. 15 is a partial sectional view showing a second electrode layer according to a further embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will be described below with reference to the drawings. In each of the drawing, the X direction coincides with the track width direction, the Y direction coincides with the direction of a leakage magnetic field from a recording medium, and Z direction coincides with the movement direction of the recording medium and the lamination direction of layers constituting a giant magnetoresistive element.

Fig. 1 is a schematic sectional view showing the structure of a giant magnetoresistive (GMR) element 1 according to a first embodiment of the present invention, as viewed from a surface facing the recording medium. The GMR element 1 is used for, for example, a thin film magnetic head of a hard disk device, for detecting a leakage magnetic field from the recording medium by utilizing a GMR effect.

The GMR element 1 is formed on a lower gap layer 2 comprising an insulating material such as alumina (Al_2O_3) or the like. The GMR element 1 comprises a seed layer 3, a first antiferromagnetic layer 4, a pinned magnetic layer 5, a nonmagnetic material layer 6, a free magnetic layer 11, a nonmagnetic layer 13, ferromagnetic layers 12, second antiferromagnetic layers 14 and electrode layers 20, which are laminated in that order on the lower gap layer 2. The nonmagnetic layer 13, the ferromagnetic layers 12 and the second antiferromagnetic layers 14 are longitudinal bias layers for the free magnetic layer 11. Although not shown in the drawing, an undercoat layer composed of alumina, an underlying layer composed of Ta, a NiFe alloy or the like, and a lower shield layer composed of a magnetic material such as a NiFe alloy or the like may be formed below the lower gap layer 2 in that order from an alumina-titanium carbide substrate.

The seed layer 3 is an underlying layer for arranging crystal growth of each of the first antiferromagnetic layer 4 and the layers laminated thereon, and comprises a NiFe alloy, a NiCr alloy, a NiFeCr alloy, Cr, or the like. The underlying layer composed of Ta or the like may be formed between the seed layer 3 and the lower gap layer 2, or the underlying layer may be formed instead of the seed layer 3.

The first antiferromagnetic layer 4 produces a great exchange coupling magnetic field between the pinned magnetic layer 5 and the first antiferromagnetic layer 4 by a heat treatment so that the magnetization direction of the pinned

magnetic layer 5 is pinned in the Y direction shown in the drawing. The first antiferromagnetic layer 4 comprises a PtMn alloy, a X-Mn (wherein X is at least one element of Pd, Ir, Rh, Ru, Os, Ni, and Fe) alloy, or a Pt-Mn-X' (wherein X' is at least one element of Pd, Ir, Rh, Ru, Au, Ag, Os, Cr, Ni, Ar, Ne, Xe, and Kr) alloy. Although these alloys have a disordered face-centered cubic structure (fcc) immediately after deposition, the fcc structure is transformed to a CuAuI-type ordered face-centered tetragonal structure (fct) by a heat treatment. Therefore, when the first antiferromagnetic layer 4 is formed by using any one of the alloys, a great exchange coupling magnetic field can be produced between the first antiferromagnetic layer 4 and the pinned magnetic layer 5 by the heat treatment.

The pinned magnetic layer 5 has a laminated ferrimagnetic pinned structure comprising a first pinned magnetic layer 5a, a nonmagnetic intermediate layer 5b and a second pinned magnetic layer 5c. In this structure, magnetization of the first pinned magnetic layer 5a is pinned in the height direction by exchange coupling with the first antiferromagnetic layer 4, and magnetization of the second pinned magnetic layer 5c is pinned in a direction at 180° (antiparallel) with respect to the magnetization direction of the first pinned magnetic layer 5a through the nonmagnetic intermediate layer 5b. With the pinned magnetic layer 5 having the laminated ferrimagnetic pinned structure, the magnetization direction of the pinned magnetic layer 5 can be stably pinned by a synergy effect of antiparallel coupling

between the first and second pinned magnetic layers 5a and 5c
through the nonmagnetic intermediate layer 5b and exchange
coupling between the first pinned magnetic layer 5a and the
first antiferromagnetic layer 4. Of course, the pinned
5   magnetic layer 5 may have a single layer structure.

Each of the first and second pinned magnetic layers 5a
and 5c comprises a ferromagnetic material, for example, a
NiFe alloy, Co, a CoNiFe alloy, a CoFe alloy, a CoNi alloy,
or the like. Particularly, each of the first and second
10   pinned magnetic layers 5a and 5c preferably comprises a CoFe
alloy or Co. Also, the first and second pinned magnetic
layers 5a and 5c preferably comprises the same material. The
nonmagnetic intermediate layer 5b comprises a nonmagnetic
material, for example, at least one of Ru, Rh, Pd, Ir, Os, Re,
15   Cr, Cu, Pt, and Au. Particularly, the nonmagnetic
intermediate layer 5b preferably comprises Ru or Cu.

The nonmagnetic material layer 6 is a layer for
preventing magnetic coupling between the pinned magnetic
layer 5 and the free magnetic layer 11, and a sensing current
20   mainly flows through the layer. The nonmagnetic material
layer 6 comprises a nonmagnetic material having conductivity,
such as Cu, Cr, Au, Ag, or the like, and particularly
preferably comprises Cu.

The free magnetic layer 11 has a central portion (track
25   width region) 11a in which magnetization can be rotated with
an external magnetic field, and both side portions 11b
provided on both sides of the central portion 11a in the
track width direction. The free magnetic layer 11 is formed

to have a larger magnetic moment (magnetic thickness) per unit area than that of the ferromagnetic layers 12. The magnitude of magnetic moment per unit area can be represented by a product of saturation magnetization M_s and thickness t.

5   The nonmagnetic layer 13 has a central portion 13a positioned on the central portion 11a of the free magnetic layer 11, and both side portions 13b positioned on the respective both side portions 11b of the free magnetic layer 11, the ferromagnetic layers 12 being formed on the both side

10   portions 13b. Both side portions 13b of the nonmagnetic layer 13 are formed to a thickness with which RKKY coupling energy produced between both side portions 11b of the free magnetic layer 11 and the ferromagnetic layers 12 is a first peak or second peak value for antiparallel alignment. Namely,

15   both side portions 11b of the free magnetic layer 11 are coupled with the respective ferromagnetic layers 12 in antiparallel to each other through both side portions 13b of the nonmagnetic layer 13 so that the magnetization directions of the free magnetic layer 11 and each ferromagnetic layer 12

20   are antiparallel to each other. The nonmagnetic layer 13 may be composed of at least one of Ru, Rh, Pd, Ir, Os, Re, Cr, Cu, Pt, and Au, and particularly preferably Ru or Cu. Although, in this embodiment, the nonmagnetic layer 13 is formed over the entire surface of the free magnetic layer 11, the

25   nonmagnetic layer 13 may be formed only on both side portions 11b of the free magnetic layer 11.

       Each of the free magnetic layer 11 and the ferromagnetic layers 12 comprises a ferromagnetic material, for example, a

NiFe alloy, Co, a CoNiFe alloy, a CoFe alloy, a CoNi alloy, or the like. The free magnetic layer 11 and the ferromagnetic layers 12 preferably comprise the same material. In the use of the same material, the thickness of each free

5   ferromagnetic layer 12 is made smaller than that of the free magnetic layer 11 so that the magnetic moment per unit area of the free magnetic layer 11 is larger than that of the ferromagnetic layers 12. With the free magnetic layer 11 and the ferromagnetic layers 12 each having a single layer

10 structure, the free magnetic layer 11 or the ferromagnetic layers 12, or both of the layers 11 and 12 preferably comprise a CoNiFe alloy. On the other hand, with the free magnetic layer 11 and the ferromagnetic layers 12 each having a multi-layer structure, the free magnetic layer 11

15 preferably comprises a laminate of a NiFe alloy and a CoFe alloy which are laminated in order, and each of the ferromagnetic layers 12 preferably comprises a laminate of a CoFe alloy and a NiFe alloy which are laminated in order.

The second antiferromagnetic layers 14 are formed on the

20 respective ferromagnetic layers 12 to produce exchange coupling magnetic fields between the second antiferromagnetic layers 14 and the respective ferromagnetic layer 12 by a heat treatment, such that the magnetization direction of each ferromagnetic layer 12 is pinned in the track width direction

25 (the rightward direction in Fig. 1). When magnetization of each ferromagnetic layer 12 is pinned, magnetizations of both side potions 11b of the free magnetic layer 11 are pinned in a direction (the leftward direction in Fig. 1; antiparallel)

opposite to the magnetization direction of the ferromagnetic layers 12 through both side portions 13b of the nonmagnetic layer 13, and the magnetization direction of the central portion 11a between both side portions 11b is aligned in antiparallel to the ferromagnetic layers 12. In this embodiment, the track width Tw is regulated by the distance between the second antiferromagnetic layers 14 in the track width direction, and the track width Tw coincides with the dimension of the central portion 11a of the free magnetic layer 11 in the track width direction.

Like the first antiferromagnetic layer 4, each of the second antiferromagnetic layers 14 comprises a PtMn alloy, a X-Mn (wherein X is at least one element of Pd, Ir, Rh, Ru, Os, Ni, and Fe) alloy, or a Pt-Mn-X' (wherein X' is at least one element of Pd, Ir, Rh, Ru, Au, Ag, Os, Cr, Ni, Ar, Ne, Xe, and Kr) alloy.

Each of the electrode layers 20 comprises a first electrode layer 21 formed on the first antiferromagnetic layer 4 to make contact with the end surfaces of the first antiferromagnetic layer 4, the pinned magnetic layer 5, the nonmagnetic material layer 6, the free magnetic layer 11 and each second antiferromagnetic layer 12 at each side in the track width direction, and a second electrode layer 22 formed on the first electrode layer 21 and each second antiferromagnetic layer 14. Each of the first and second electrode layers 21 and 22 comprises a conductive material having low resistivity, for example, Au, Cu, α-Ta, Cr, or the like. The sensing current supplied to the second

electrode layers 22 flows into the nonmagnetic material layer 6, the free magnetic layer 11 and the pinned magnetic layer 5 through the respective first electrode layers 21.

Although not shown in the drawing, an upper shield layer
5   is formed on the second electrode layers 22 and the central portion 13a of the nonmagnetic layer 13 through an upper gap layer composed of, for example, alumina.

The above-described GMR element 1 is characterized in that at least the free magnetic layer 11, the nonmagnetic
10 layer 13 and the ferromagnetic layers 12 have continuous end surfaces α at both sides in the track width direction. In this way, when both ends are the continuous surfaces, magnetostatic coupling can be produced between the free magnetic layer 11 and each ferromagnetic layer 12 at both end
15 surfaces, and thus a demagnetizing field applied to the free magnetic layer 11 in the track width direction thereof can be weakened by the magnetostatic coupling. Therefore, even when the dimension FW of the free magnetic layer 11 in the track width direction is decreased by narrowing the track,
20 disturbance of magnetization at both end surfaces of the free magnetic layer and the ferromagnetic layer 12 and disturbance of magnetization within the track width region can be suppressed.

The GMR element 1 is also characterized in that the
25 ratio (FW/FL) of the dimension FW of the free magnetic layer 11 in the track width direction to the dimension FL of the ferromagnetic layers 12 in the track width direction is 1.1 to 2.0. The dimension FL of the ferromagnetic layers 12 in

the track width direction is a total dimension (FL1+FL2) of a

pair of the ferromagnetic layers 12 shown in Fig. 1. With

the ratio (FW/FL) within the above range, magnetizations of

both side portions 11b of the free magnetic layer 11 can be

5   appropriately pinned by antiparallel coupling with the

ferromagnetic layers 12, and magnetization rotation in the

central portion 11a of the free magnetic layer 11 can be

facilitated with the external magnetic field. Therefore, a

distortion and instability of the reproduction waveform can

10   be suppressed to improve output sensitivity, and the

occurrence of side reading can be prevented. The

magnetization rotation in the central portion 11a of the free

magnetic layer 11 is further facilitated by weakening RKKY

antiparallel coupling between both side portions 11b of the

15   free magnetic layer 11 and the ferromagnetic layers 12,

thereby further improving the output sensitivity. The

strength of antiparallel coupling between the ferromagnetic

layers 12 and both side portions 11b of the free magnetic

layer 11 can be controlled by controlling the thickness of

20   both side portions 13b of the nonmagnetic layer 13.

       The GMR element 1 is further characterized in that the

electrode layers 20 are formed in contact with the tops of

the respective second antiferromagnetic layers 14 and the end

surfaces of the layers ranging from the second

25   antiferromagnetic layers 14 to the pinned magnetic layer 5 at

both sides in the track width direction, and thus the sensing

current is supplied without passing through the second

antiferromagnetic layers 14. When the sensing current is

supplied without passing through the second antiferromagnetic layers 14, the element resistance can be decreased, as compared with a conventional element in which a sensing current is supplied through the second antiferromagnetic layers 14. As a result, the occurrence of high-frequency noise can be suppressed to improve the SN ratio.

The method of manufacturing the GMR element shown in Fig. 1 will be described with reference to Figs. 2 to 8. First, the seed layer 3, the first antiferromagnetic layer 4, the fist pinned magnetic layer 5a, the nonmagnetic intermediate layer 5b and the second pinned magnetic layer 5c constituting the pinned magnetic layer 5, the nonmagnetic material layer 6, the free magnetic layer 11, and the nonmagnetic layer 13 are continuously deposited on the lower gap layer 2 composed of alumina (Fig. 2). This continuous deposition step is performed by a thin film forming process such as sputtering, evaporation, or the like in a same vacuum deposition apparatus.

The seed layer 3 comprises a NiFe alloy, a NiCr alloy, a NiFeCr alloy, Cr, or the like. The first antiferromagnetic layer 4 comprises a PtMn alloy, a X-Mn (wherein X is at least one element of Pd, Ir, Rh, Ru, Os, Ni, and Fe) alloy, or a Pt-Mn-X' (wherein X' is at least one element of Pd, Ir, Rh, Ru, Au, Ag, Os, Cr, Ni, Ar, Ne, Xe, and Kr) alloy. With the first antiferromagnetic layer 4 comprising any one of these alloy materials, a large exchange coupling magnetic field can be produced in magnetic field annealing in a subsequent step.

Each of the first and second pinned magnetic layers 5a

and 5c may comprise a magnetic material, for example, a NiFe alloy, Co, a CoNiFe alloy, a CoFe alloy, a CoNi alloy, or the like, and the first and second pinned magnetic layers 5a and 5b preferably comprise the same material. The nonmagnetic

5 intermediate layer 5b may comprise any one of Ru, Rh, Pd, Ir, Os, Re, Cr, Cu, Pt, and Au, and particularly preferably comprises Ru or Cu. The pinned magnetic layer 5 may comprise a single ferromagnetic material layer.

The nonmagnetic material layer 6 may comprise a

10 nonmagnetic material having conductivity, for example, Cu, Cr, Au, Ag, or the like. Particularly, the nonmagnetic material layer 6 preferably comprises Cu. The free magnetic layer 11 may comprise any one of a NiFe alloy, Co, a CoFe alloy, a CoNi alloy, and a CoFeNi alloy. The nonmagnetic layer 13 may

15 comprise any one of Ru, Rh, Pd, Ir, Os, Re, Cr, Cu, Pt, and Au, and particularly preferably comprises Ru or Cu. The nonmagnetic layer 13 is deposited to a thickness larger than that in the completed state shown in Fig. 1.

After the nonmagnetic layer 13 is deposited, a first

20 heat treatment is performed. Namely, a heat treatment is performed at a first heat treatment temperature with a first magnetic field applied in a direction (height direction; the Y direction shown in the drawing) perpendicular to the track width direction to produce an exchange coupling magnetic

25 field between the first antiferromagnetic layer 4 and the first pinned magnetic layer 5a, for pinning magnetization of the first pinned magnetic layer 5a in the height direction.

After the annealing treatment, as shown in Fig. 3, the

surface of the nonmagnetic layer 13 is cleaned by low-energy

ion milling. In this embodiment, low-energy ion milling is

performed by using Ar ions accelerated with, for example, 100

to 200 eV. In this step, the nonmagnetic layer 13 is

5   controlled to a thickness with which RKKY coupling energy

produced between the free magnetic layer 11 and the

ferromagnetic layer 12 through the nonmagnetic layer 13 is a

first peak value (or second peak value) for antiparallel

alignment. For example, when the nonmagnetic layer 13 is

10 composed of Ru, the thickness is preferably controlled to 6 Å

to 12 Å, while when the nonmagnetic layer 13 is composed of

Cu, the thickness is preferably controlled to 7 Å to 12 Å.

In Fig. 3, the ion milling direction is shown by arrows H.

Next, as shown in Fig. 4, the ferromagnetic layer 12 and

15 the second antiferromagnetic layer 14 are continuously

deposited on the nonmagnetic layer 13 by sputtering or

evaporation.

The ferromagnetic layer 12 preferably comprises the same

material as the free magnetic layer 11. When the free

20 magnetic layer 11 and the ferromagnetic layer 12 comprise the

same material, the ferromagnetic layer 12 is formed to a

smaller thickness than that of the free magnetic layer 11 so

that the magnetic moment per unit area of the free magnetic

layer 11 is larger than that of the ferromagnetic layer 12.

25 Each of the free magnetic layer 11 and the ferromagnetic

layer 12 may be formed in a single layer structure or multi-

layer structure. With the free magnetic layer 11 and the

ferromagnetic layer 12 each having a single layer structure,

at least one of the free magnetic layer 11 and the ferromagnetic layer 12 preferably comprises a CoNiFe alloy. On the other hand, with the free magnetic layer 11 and the ferromagnetic layer 12 each having a multi-layer structure, the free magnetic layer 11 preferably comprises a laminate of a NiFe alloy and a CoFe alloy which are laminated in order, and the ferromagnetic layer 12 preferably comprises a laminate of a CoFe alloy and a NiFe alloy which are laminated in order.

Then, a photoresist solution is coated on the second antiferromagnetic layer 14, and then patterned in the track width region by exposure and development to form a resist layer R shown in Fig. 5 at a position corresponding to the track width region. The resist layer R is a lift off resist layer. After the resist layer R is formed, ion milling is performed until the first antiferromagnetic layer 4 is exposed from both sides of the resist layer R in the track width direction (Fig. 5). In Fig. 5, the ion milling direction is shown by arrows H. The ion milling may be continued until the seed layer 3 or the lower gap layer 2 is exposed.

In the ion milling step, the portions shown by dotted lines in Fig. 5 out of the track width region (portions of the second antiferromagnetic layer 14, the ferromagnetic layer 12, the nonmagnetic layer 13, the free magnetic layer 11, the nonmagnetic material layer 6, the pinned magnetic layer 5 and the first antiferromagnetic layer 4) are removed. As a result, the dimension FW of the free magnetic layer 11

in the track width direction is regulated, and the layers
ranging from the second antiferromagnetic layer 14 to the
first antiferromagnetic layer 4 have the continuous end
surfaces α at both sides in the track width direction. When
5   the continuous end surfaces α are formed, magnetostatic
coupling can be produced between the free magnetic layer 11
and the ferromagnetic layer 12 at both end surfaces 11c and
12c of the free magnetic layer 11 and the ferromagnetic layer
12, and thus the influence of a demagnetizing field in both
10   side portions of the free magnetic layer 11 and the
ferromagnetic layer 12 can be decreased by the magnetostatic
coupling.

　　　Then, as shown in Fig. 6, the first electrode layers 21
are formed on the first antiferromagnetic layer 4 to make
15   contact with the end surfaces of the layers ranging from the
second antiferromagnetic layer 14 to the first
antiferromagnetic layer 4 at both sides in the track width
direction. Each of the first electrode layers 21 may
comprise a conductive material having low resistivity, for
20   example, Au, Cu, α-Ta, Cr, or the like.

　　　After the first electrode layers 21, the resist layer R
is removed by liftoff, and the second electrode layers 22 are
formed on the first electrode layers 21 and regions of the
second antiferromagnetic layer 14 out of the track width
25   region, as shown in Fig. 7. Namely, a second electrode layer
22 and metal mask layer 23 are formed on the first electrode
layers 21 and the second antiferromagnetic layer 14, and then
the metal mask layer 23 and the second electrode layer 22 are

removed from the track width region by reactive ion etching. The second electrode layers 22 preferably comprise the same conductive material as that of the first electrode layers 21. The second electrode layers 22 can be formed by a liftoff

5   method. In the liftoff method, the metal mask layers 23 need not be formed.

When the sensing current is supplied to the second electrode layers 22, the sensing current flows into the nonmagnetic material layer 6, the pinned magnetic layer 5 and

10 the free magnetic layer 11 through the first electrode layers 21 having low resistivity. Namely, the sensing current can be supplied without passing through the second antiferromagnetic layer 14 having extremely higher resistivity than the electrode layers 20. Therefore, the

15 element resistance of the GMR element 1 to be formed can be sufficiently suppressed to avoid a decrease in the SN ratio due to high-frequency noise.

After the second electrode layers 22 are formed, as shown in Fig. 8, reactive ion etching (RIE) treatment is

20 performed by using the metal mask layers 23 and the second electrode layers 22 as masks to remove the second antiferromagnetic layer 14, the ferromagnetic layer 12 and the nonmagnetic layer 13 from the track width region. In this embodiment, the reactive ion etching is stopped when the

25 thickness of the nonmagnetic layer 13 (central portion 13a) in the track width region becomes 3 Å or less. The nonmagnetic layer 13 may be completely removed from the track width region, and ion milling may be performed in place of

the reactive ion etching.

In the reactive ion etching step, the portions shown by dotted lines in Fig. 8 are moved to form a recess β. Namely, the ferromagnetic layer 12 and the second antiferromagnetic layer 14 are present only on both side portions 11b of the free magnetic layer 11. Therefore, the track width Tw is regulated by the distance between the second antiferromagnetic layers 14 in the track width direction, and the dimension FL of the ferromagnetic layers 12 in the tack width direction is regulated.

In this embodiment, the ratio (FW/FL) of the dimension FW of the free magnetic layer 11 in the tack width direction to the dimension FL of the ferromagnetic layers 12 in the track width direction is set to 1.1 to 2.0 so as to appropriately pin magnetization of each side portion 11b of the free magnetic layer 11 and facilitate magnetization rotation of the central portion 11a with the external magnetic field.

Then, a second heat treatment is performed. In this step, a heat treatment is performed at a second heat treatment temperature lower than the blocking temperature of the first antiferromagnetic layer 4 with a second magnetic field applied in a direction (track width direction) perpendicular to the first magnetic field, the second magnetic field being higher than the coercive force of the free magnetic layer 11 and the ferromagnetic layer 12 and lower than the flip flop magnetic field. In this heat treatment, an exchange coupling magnetic field is produced

between the ferromagnetic layers 12 and the second antiferromagnetic layers 14 to pin the magnetization directions of the ferromagnetic layers 12 in a direction perpendicular to the magnetization direction of the pinned

5   magnetic layer 5.   The second heat treatment may be performed immediately after the step shown in Fig. 4.   The GMR element shown in Fig. 1 is obtained by the above-described steps.

Fig. 9 is a partial sectional view showing the structure of a GMR element 100 according to a second embodiment of the

10   present invention, as viewed from a surface facing a recording medium.   The second embodiment is different from the first embodiment in that each of the second antiferromagnetic layers 14 comprises a lower antiferromagnetic layer 14a and an upper antiferromagnetic

15   layer 14b.   In Fig. 9, substantially the same components as in the first embodiment are denoted by the same reference numerals.

A nonmagnetic protective layer 15 may be interposed between the lower antiferromagnetic layer 14a and the upper

20   antiferromagnetic layer 14b.   The nonmagnetic protective layer 15 is provided as an antioxidation layer for preventing oxidation of the lower antiferromagnetic layer 14a in the manufacturing process, and is formed to a thickness of 3 Å or less.   The constituent elements of the nonmagnetic protective

25   layer 5 may diffuse into the lower antiferromagnetic layer 14a and/or upper antiferromagnetic layer 14b in a heat treatment for producing the exchange coupling magnetic field between the ferromagnetic layer 12 and the lower

antiferromagnetic layer 14a, and may be mixed in the lower antiferromagnetic layer 14a and/or upper antiferromagnetic layer 14b.

The upper antiferromagnetic layer 14b is coupled with the lower antiferromagnetic layer 14a through the nonmagnetic protective layer 15 to function integrally with the lower antiferromagnetic layer 14a. The lower antiferromagnetic layer 14a is preferably formed to a thickness of 20 Å to 50 Å so as not to assume the antiferromagnetic properties in the stage in which only the lower antiferromagnetic layer 14a is deposited. Also, the total thickness of the lower antiferromagnetic layer 14 and the upper antiferromagnetic layer 14b is preferably 80 Å to 300 Å so as to produce a large exchange coupling magnetic field between the ferromagnetic layer 12 and the lower antiferromagnetic layer 14a by a heat treatment.

The lower antiferromagnetic layer 14a and the upper antiferromagnetic layer 14b preferably comprise the same material such as a PtMn alloy, a X-Mn (wherein X is at least one element of Pd, Ir, Rh, Ru, Os, Ni, and Fe) alloy, or a Pt-Mn-X' (wherein X' is at least one element of Pd, Ir, Rh, Ru, Au, Ag, Os, Cr, Ni, Ar, Ne, Xe, and Kr) alloy. On the other hand, the nonmagnetic protective layer 15 may comprise at least one of Ru, Rh, Pd, Ir, Os, Re, Cr, Cu, Pt, and Au, and particularly preferably comprises Ru or Cr. In the combination of the material for the lower antiferromagnetic layer 14a and the upper antiferromagnetic layer 14b and the material for the nonmagnetic protective layer 15, the lower

and upper antiferromagnetic layers 14a and 14b integrally

function to produce a large exchange coupling magnetic field

between the ferromagnetic layer 12 and these

antiferromagnetic layers 14a and/or 14b even when the

5   constituent elements of the nonmagnetic protective layer 15

diffuse into the lower antiferromagnetic layer 14a and/or the

upper antiferromagnetic layer 14b to increase the

concentration of the elements of the nonmagnetic protective

layer 15 near the interface between the lower

10   antiferromagnetic layer 14a and/or the upper

antiferromagnetic layer 14b.

The method of manufacturing the GMR element 100 shown in

Fig. 9 will be described below with reference to Figs. 10 to

13.   First, the seed layer 3, the first antiferromagnetic

15   layer 4, the first pinned magnetic layer 5a, the nonmagnetic

intermediate layer 5b and the second pinned magnetic layer 5c

constituting the pinned magnetic layer 5, the nonmagnetic

material layer 6, the free magnetic layer 11, the nonmagnetic

layer 13, the ferromagnetic layer 12, the lower

20   antiferromagnetic layer 14a and the nonmagnetic protective

layer 15 are continuously deposited on the lower gap layer 2

composed of alumina (Fig. 10).   This continuous deposition

step is performed by a thin film forming process such as

sputtering, evaporation, or the like in a same vacuum

25   deposition apparatus.

Since the materials and thicknesses of the seed layer 3,

the first antiferromagnetic layer 4, the first pinned

magnetic layer 5a, the nonmagnetic intermediate layer 5b, the

second pinned magnetic layer 5c, the nonmagnetic material layer 6, the free magnetic layer 11, the nonmagnetic layer 13 and the ferromagnetic layer 12 are the same as those in the first embodiment, the description of these layers is omitted.

5   Like the first antiferromagnetic layer 4, the lower antiferromagnetic layer 14a comprise a PtMn alloy, a X-Mn (wherein X is at least one element of Pd, Ir, Rh, Ru, Os, Ni, and Fe) alloy, or a Pt-Mn-X' (wherein X' is at least one element of Pd, Ir, Rh, Ru, Au, Ag, Os, Cr, Ni, Ar, Ne, Xe,

10   and Kr) alloy. The lower antiferromagnetic layer 14a is preferably formed to a thickness of 20 Å to 50 Å. With a thickness in this range, in a stage in which only the lower antiferromagnetic layer 14a is formed on the ferromagnetic layer 12, a heat treatment produces no (or a weak) exchange

15   coupling magnetic field occurs between the ferromagnetic layer 12 and the lower antiferromagnetic layer 14a.

The nonmagnetic protective layer 15 is provided as a protective layer (antioxidation layer) for preventing oxidation of the lower antiferromagnetic layer 14a, and is

20   preferably formed to a thickness of 3 Å to 10 Å. The nonmagnetic protective layer 15 may comprise at least one of Ru, Rh, Pd, Ir, Os, Re, Cr, Cu, Pt, and Au, and particularly preferably comprises Ru or Cr.

After the nonmagnetic protective layer 15 is formed, a

25   first heat treatment is performed. Namely, a heat treatment is performed at a first heat treatment temperature with a first magnetic field applied in a direction (height direction; the Y direction shown in the drawing)

perpendicular to the track width Tw to produce an exchange
coupling magnetic field between the first antiferromagnetic
layer 4 and the first pinned magnetic layer 5a, for pinning
magnetization of the first pinned magnetic layer 5a. In this
5 step, the lower antiferromagnetic layer 14a is less ordered
by the first heat treatment because it has a small thickness
so as not to assume the antiferromagnetic properties, as
described above, thereby producing no (or a weak) exchange
coupling magnetic field between the lower antiferromagnetic
10 layer 14a and the ferromagnetic layer 12.

Then, as shown in Fig. 11, the surface of the
nonmagnetic protective layer 15 is cleaned by low-energy ion
milling. In this step, the nonmagnetic protective layer 15
is controlled to a thickness of 3 Å or less.

15 Next, as shown in Fig. 12, the upper antiferromagnetic
layer 14b is formed on the lower antiferromagnetic layer 14a
with the nonmagnetic protective layer 15 provided
therebetween. The upper antiferromagnetic layer 14b is
preferably formed so that the total thickness of the upper
20 antiferromagnetic and lower antiferromagnetic layers 14b and
14a is 80 Å to 300 Å. With a total thickness in this range,
the lower antiferromagnetic layer 14a and upper
antiferromagnetic layer 14b can integrally function as the
second antiferromagnetic layer 14 to produce a large exchange
25 coupling magnetic field between the lower antiferromagnetic
layer 14a and the ferromagnetic layer 12 by the heat
treatment. When the nonmagnetic protective layer 15 is
completely removed by the low-energy ion milling step shown

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in Fig. 11, the upper antiferromagnetic layer 14b is formed directly on the lower antiferromagnetic layer 14a.

After the upper antiferromagnetic layer 14b is formed, as shown in Fig. 13, a photoresist layer R is formed on the

5   upper antiferromagnetic layer 14b, and then ion milling is performed until the first antiferromagnetic layer 14 is exposed from both sides of the resist layer R in the track width direction (Fig. 13). In Fig. 13, the ion milling direction is shown by arrows H. In the ion milling step,

10 portions of each layer shown by dotted lines in Fig. 13 out of the track width region are removed. As a result, the dimension FW of the free magnetic layer 11 in the track width direction is regulated, and the layers ranging from the upper antiferromagnetic layer 14b to the first antiferromagnetic

15 layer 4 have the continuous end surfaces α at both sides in the track width direction, thereby producing magnetostatic coupling between the free magnetic layer 11 and the ferromagnetic layer 12 at both side end surfaces 11c and 12c. The ion milling may be performed until the seed layer 3 or

20 the lower gap layer 2 is exposed.

Then, the first and second electrode layers 21 and 22 are formed, and then the upper antiferromagnetic layer 14b, the nonmagnetic protective layer 15, the lower antiferromagnetic layer 14a, the ferromagnetic layer 12 and

25 the nonmagnetic layer 13 are removed from the track width region by the same steps as those (Fig. 6 to 8) in the first embodiment. As a result, the track width Tw is regulated by the distance between the upper antiferromagnetic layers 14b,

the nonmagnetic protective layers 15 and the lower

antiferromagnetic layers 14a, and the dimension FL of the

ferromagnetic layers 12 in the tack width direction is

regulated.

5   Then, a second heat treatment is performed. In this

step, a heat treatment is performed at a second heat

treatment temperature lower than the blocking temperature of

the first antiferromagnetic layer 4 with a second magnetic

field applied in a direction (track width direction)

10   perpendicular to the first magnetic field. In this heat

treatment, the constituent element of the nonmagnetic

protective layer 15 may diffuse into the lower

antiferromagnetic layer 14a and/or upper antiferromagnetic

layer 14b, and may be mixed in the lower antiferromagnetic

15   layer 14a and/or upper antiferromagnetic layer 14b. This

second heat treatment may be performed immediately after the

step shown in Fig. 12. The GMR 100 shown in Fig. 9 is

obtained by the above-described steps.

      Although, in each of the above embodiments, the

20   electrode layer 20 comprises the first and second electrode

layers 21 and 22, the electrode layer 20 may have a single

layer structure. Namely, only the first electrode layer 21

or the second electrode layer 22 may be formed. When only

the second electrode layer 22 is formed, the resist layer R

25   is removed after the continuous end surfaces α are formed in

the step shown in Fig. 5 or 13, and then the second electrode

layer 22 is formed on regions of the second antiferromagnetic

layer 14 out of the track width region and on the continuous

end surfaces α, as shown in Fig. 14. In any one of the
cases, the sensing current can be supplied without passing
through the second antiferromagnetic layers 14 to
sufficiently suppress the element resistance. The electrode
5   layer 20 (second electrode layer 22) may be formed to have
ends overlaid on the free magnetic layer 11. In this
overlaid structure, the element resistance can be further
decreased, and the occurrence of side reading can be
sufficiently prevented.

10   Although, in each of the above embodiments, the
thickness of both side portions 13b of the nonmagnetic layer
13 is controlled to appropriately decrease antiparallel
coupling between the free magnetic layer 11 and the
ferromagnetic layer 12, thereby facilitating rotation in the
15   central portion 11a of the free magnetic layer 11 and
improving the output sensitivity. Since magnetostatic
coupling occurs between the free magnetic layer 11 and the
ferromagnetic layer 12 at both end surfaces in the track
width direction, the occurrence of side reading can be
20   sufficiently prevented even when antiparallel coupling
between the free magnetic layer 11 and the ferromagnetic
layer 12 is weakened.

         The above-described GMR element (100) of the present
invention can be applied not only to a reproducing thin film
25   magnetic head but also to a recording/reproducing thin film
magnetic head comprising the reproducing thin film magnetic
head and a recording inductive head laminated thereon. The
GMR element can also be used as any one of various magnetic

sensors.

In the present invention, at least a free magnetic layer, a non magnetic layer and a ferromagnetic layer are formed to have continuous end surfaces at both sides in the tack width direction, and thus magnetostatic coupling occurs between the free magnetic layer and the ferromagnetic layer at both end surfaces. Therefore, the influence of a demagnetizing field applied to the free magnetic layer and the ferromagnetic layer can be decreased by the magnetostatic coupling. Thus, even when the dimension of the free magnetic layer in the track width direction is decreased for realizing a narrower track, a disturbance of magnetization within the track width region can be suppressed to improve output sensitivity. Also, in the present invention, the ratio (FW/FL) of the dimension of the free magnetic layer to the dimension of the ferromagnetic layer in the track width direction is regulated to 1.1 to 2.0, and thus the output sensitivity can be improved while sufficiently suppressing a distortion and instability of a reproduction waveform. Furthermore, in the present invention, the sensing current is supplied without passing through a second antiferromagnetic layer having high resistivity, and thus the element resistance can be sufficiently decreased, thereby suppressing high-frequency noise and improving the SN ratio.